ND STEM
TEACHING FELLOWS

How Small is Small?

Nanoparticles Curriculum Package

*Prepared by **Silvia Kenna**, **Melissa Kwan**, and **Donna Terrasi** as part of the Notre Dame STEM Teacher Residency Program*

UNIVERSITY OF NOTRE DAME

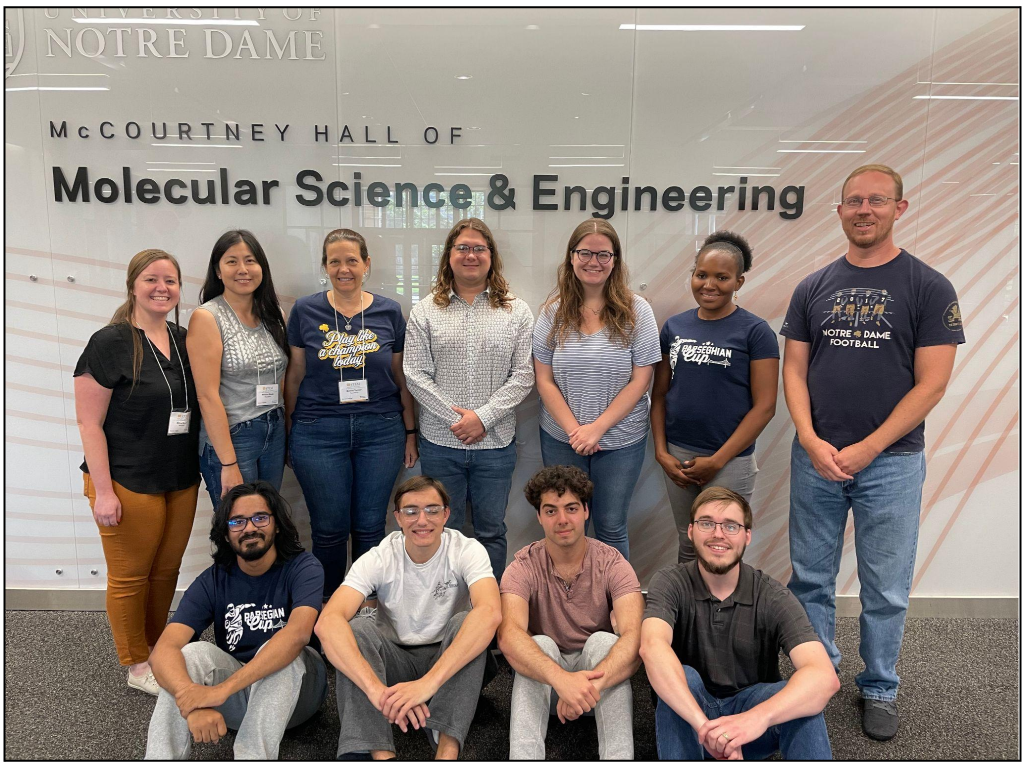
Table of Contents

"I loved learning about nanoparticles and technology, and I would LOVE continuing this path this year in class and would love learning more about what scientists are doing with this information." **- 7th grade student**

Acknowledgements

We would like to thank the University of Notre Dame Center for STEM Education, the STEM Teaching Fellows Program Core Team, and the Camden Research Group for providing us with this incredible opportunity. We would also like to thank our fellows in the program for all the support they have given us throughout this process, with a special thank you to Jessica Gastelum, Gabriel Cambert, and Christina Williams. Additionally, we owe tremendous thanks to the students and administrators at Blessed Trinity Catholic School, Lincoln Acres Elementary, and Saint Clement School. Finally, we are grateful to our families for allowing us the time and flexibility to travel to Notre Dame and work on this project.

This material is based upon work supported by the National Science Foundation under Grant Number 2108330. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.



Senior Fellows Silvia Kenna (back row, first on left), Melissa Kwan (back row, second from left), and Donna Terrasi (back row, third from left), with the Camden Lab during their Senior Fellows Residency in Summer 2022. Photo credit: Camden Lab

For more information about the work of Notre Dame STEM Teaching Fellows, please visit stemeducation.nd.edu/fellows.

Preface and Rationale

This Curriculum Package was created by three teachers for the purpose of introducing middle grade students to current scientific research. It was developed as a result of the partnership between the University of Notre Dame's STEM Teaching Fellowship Summer Residency Program for Senior Fellows and the Camden Research Group. As part of their NSF grant, Dr. Jon Camden and his graduate students hosted three teachers for a week during Summer 2022 to shadow them in the lab and learn about their nanoparticle research. The teachers developed standards-based lessons to bring back the research into their classrooms. During the 2022-2023 academic year, they met twice a semester with members of the STEM Teaching Fellows Core Team, shared their experience of lesson implementation, and ultimately collaboratively integrated their lessons into this Curriculum Package.

Senior Fellows in the Camden Lab

University of Notre Dame's STEM Teaching Fellowship

The Notre Dame STEM Teaching Fellowship forms STEM teacher leaders who catalyze rigorous, equity-centered, and sustainable STEM learning cultures for their students and school communities. The three-year fellowship targets school teams of 3-5 STEM teachers in the middle grades. Participants from around the country attend three Summer Institutes at Notre Dame and receive two academic years of instructional coaching, strategic plan development, and leadership formation. Fellows also gather mid-year for four days of in-person professional development. Upon completion of the program, Fellows have a path to continuous growth through the 'Senior Fellows' opportunities - including on-campus professional learning such as the Summer Residency Program.

Camden Group Research Project

This collaboration of Senior Fellows with the Camden Research Group is part of the broader impacts component of an NSF grant on nanoparticles between the Camden Research Group at the University of Notre Dame and Dr. David Jenkins's research group at the University of Tennessee. According to Dr. Camden, these groups are currently "investigating the deposition of CO_2-adducted carbenes on nanoscale roughened gold substrates, further generating the first NHC SERS spectra."

Bringing Nanoscience into the Classroom

Why Teach Nanoparticles?

Nanoscience is a field of study with which many are unfamiliar. By introducing students to these concepts at a level that they are able to understand, we hope to inspire young minds to see the world around them with a deeper sense of awe and possibly even to want to learn more about the STEM fields that work with nanoparticles. Learning about current research can open their eyes to new opportunities and interests. This exposure can, in turn, encourage young children to pursue careers in STEM fields. Nanoparticle research is tied to a variety of STEM disciplines and careers, such as chemistry, molecular biology, biomedical engineering, technology, and computer science, to name a few. Because of its broad range of connections, the topic of nanoparticles is accessible to a wide variety of students across different age groups and content areas.

Definitions

- *Nanoparticle:* matter so small it cannot be seen with the naked eye and is measured on the nanoscale, which uses units called nanometers (nm); 1 nm = 1 billionth of a meter
- *Nanoscience*: the study of the properties of matter at the nanoscale

Nanoscience Overview

Although the effects of nanoscience have been studied for centuries, advances in microscopy have allowed scientists to expand our understanding of nanoparticles, their properties, and their applications. Nanoparticles are too small to be observed with a standard light microscope and require more sophisticated microscopes (e.g., a scanning electron microscope) to study them. For context, the diameter of a single strand of hair is about 100,000 nm. When materials are broken down to the nanoscale, their properties may change. Scientists study these changes and use the special properties of the materials on the nanoscale (nanomaterials) to develop new products and solve problems. This application is called nanotechnology.

Nanoparticles from dark field microscopy; photo credit: Camden Lab

Societal Impact of Nanotechnology

Nanotechnology research can help develop processes and materials to improve the quality of our lives. Some areas to which nanotechnology has been applied are electronics, energy use and conversion, engineering, building, biocompatible sensors, water-resistant coatings, medicine, and antibacterial materials. Although there are many benefits to using nanotechnology in our world, there can be negative effects as well. For example, silver nanoparticles can kill helpful bacteria used in water treatment or react with light to harm your skin. Furthermore, any new advances may have harmful effects that are not yet known and are difficult to anticipate.

Applications and Connections

What are some different applications of nanoparticle research? What connections might you be able to make between nanoparticle research and what you are already teaching?

Science	**Topical Connections** - Nature of Science - <u>Biology</u> ➢ e.g. organism adaptations, microscopes, cells and cell division, immune system - biomarkers, genetics - DNA and RNA - <u>Physical Science/Physics</u> ➢ e.g. solar and light energy, waves, visible light/astronomy, matter and its interactions	- <u>Chemistry</u> ➢ e.g. materials chemistry, physical and chemical properties - <u>Environmental Science</u> ➢ e.g. human impact, climate and alternative energy sources, environmental clean-up
Technology	**Tools** - Microscopy - Image Processing Program - imageJ Software - Spreadsheets	**Applications** - Electronic devices (e.g. screens and displays, microchips) - Semiconductors - Circuits - Communications - Robotics - Sensors
Engineering	**Topical Connections** - Engineering Design: Scale and structure; architecture (e.g. hierarchical structure)	**Applications** - Medicine: sensing, diagnosing, and treating diseases (e.g. cancer)
Math	**Topical Connections** - Scale (nano)/Place Value - Scientific Notation - Measurement - Equality/Equations - Proportionality - Statistics	

Curriculum connections can extend beyond STEM into other subject areas. For example, research and communication skills can be developed in language arts classes. The beauty of nature can be examined through nanoparticle study in both theology and art classes, and a discussion of social justice as related to nanoscience can extend across multiple content areas.

Detailed Lesson Plans

The following section contains a number of lessons developed by a team of Senior Fellows from the University of Notre Dame's STEM Teaching Fellows Program.

Each lesson will be targeted towards a specific grade level and content area; however, many of these activities are adaptable to a variety of grade level standards.

Our unit begins with two alternatives for introductory lessons. These lessons are applicable across grade levels. Following the introductory lessons are a selection of math and science lessons aligned to grade level standards. For each lesson, the first page includes a list of standards, connections and/or applications, lesson objectives, and materials needed. The next section includes the detailed lesson plan, which is followed by an assessment and helpful resources. Each lesson includes a teacher reflection from one of the Senior Fellows who taught the lesson. You will notice quotes from students mixed in; these are from students of the Senior Fellows who implemented these lessons during the 2022-2023 academic year.

The lessons on the following pages are as follows:

- *Introductory Lesson: How Small Is Small? Bringing Nanoparticle Research to Your Classroom (K-12: Adaptable)*
- *Alternative Introductory Lesson: How Small Is Small? Bringing Nanoparticle Research to Your Classroom (K-12: Adaptable)*
- *5th Grade Math: Line Plots - Examining Nanoparticles*
- *5th-6th Grade Math: Metric Conversions and Powers of 10*
- *6th-8th Grade Physical Science: Light and Its Properties*
- *8th Grade Math: Scientific Notation - Analyzing Nanoparticle Size*

ND STEM
TEACHING FELLOWS

Introductory Lesson:
How Small Is Small? Bringing Nanoparticle Research to Your Classroom (K-12: Adaptable)

Standards:
- **2-PS1-3.** Make observations to construct an evidence-based account of how an object made of a small set of pieces can be disassembled and made into a new object.
- **5-PS1-1.** Develop a model to describe that matter is made of particles too small to be seen.
- **MS-PS1-2.** Analyze and interpret data on the properties of substances.
- **CCSS.ELA.SL.1** (all grade levels) Participate and engage effectively in collaborative conversations with diverse partners about grade-level topics and texts with peers and adults in small and larger groups.

Connections to Nature of Science:
- Scientific knowledge is open to revision in light of new evidence.
- Science is a human endeavor.
- Science addresses questions about the natural and material world.

Connections to Engineering, Technology, and Applications of Science:
- Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.
- The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values and by the findings of scientific research.

Objectives:
Students will be able to understand the relative size of a nanoparticle.
Students will analyze the way properties of a material can change with the size of a particle.
Students will be able to identify different ways that nanoparticles might be used.

Lesson Plan

Estimated Time: 2 days

Hook:

Compare image from dark field microscopy with image from new Webb telescope (see photos at the end of this lesson under Resources).

- Discussion Guide with Pear Deck Slides
- Discussion questions:
  - *What do you see? (wait time)*
  - *What if I told you that these are images of two totally different things?*
  - *I notice… I wonder…*
- Repeat with SEM image and similar Webb telescope image.

> ***Teacher Tip:***
> *In order for students to truly experience the puzzling phenomenon of the hook, you may want to title this lesson something neutral. You want to be careful not to give away that the images are of nanoparticles by using it in your introduction, lesson title, or shared objectives.*

Activity:

- After the hook discussion, share with students where the images came from. Watch the video about what is nano? Explain what a nanoparticle is (use interactive scale image) Explain how the same particle can change color as it is broken into smaller pieces, and that that is what is shown in the dark field microscopy image.
- *Optional*: Students will work in groups to compare crystalline sugar and powdered sugar to help students connect the idea that when a material is broken down into smaller parts its properties can change.
  - Supplies
    - One paper plate per student group (or some firm surface on which students can examine sugar samples)
    - One solid sugar cube per group
    - Some crystalline sugar
    - Some powdered sugar
    - Hand lens (or microscope if accessible) – one per group
    - Flashlight or other source of bright light – one per group
  - Procedure
    - Create a 3-column chart to record observations and comparisons.
    - Give students a sugar cube on a paper plate to examine with a hand lens; have them look carefully at it with a flashlight as well. **Teachers may opt to view samples through a microscope, instead of a hand lens*.
    - Then give students a sample of both crystalline and powdered sugar to examine with a hand lens.
    - Discuss observations comparing the substances; identify that these are basically the same substances, just different sized particles and how the properties change and affect the use of each type of sugar.

- Introduce the concept of nanotechnology by explaining that scientists use the different properties of nanoparticles to create new materials to solve problems in our world. Assign different videos to groups to learn about various nanotechnology applications. Students then report to the class on what they've learned.

"They were fun to look at how nanometers are used to measure tiny objects."

- 5th Grade Student

Assessment:

Exit slip (index card or Google Form)

1. What did you learn from the video about the size of a nanoparticle?
2. Using evidence from the sugar activity, explain how the properties of the sugar changed with the size of the sugar particles.
3. Describe your favorite way nanomaterials can be used in our world.

Resources:

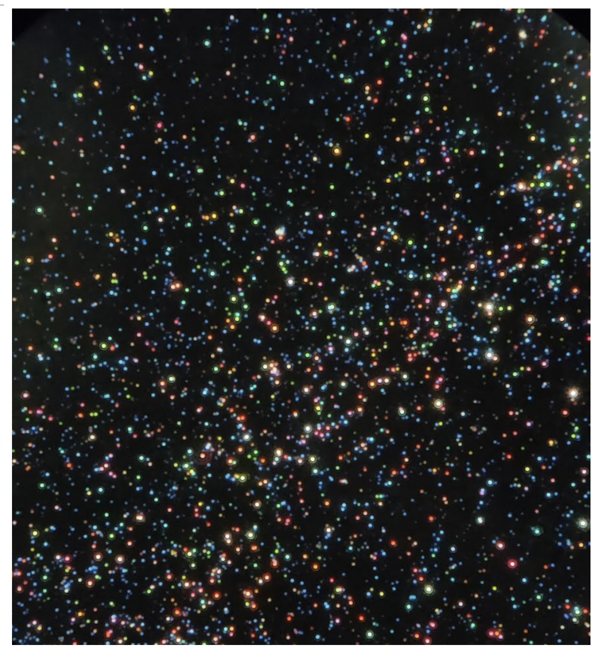
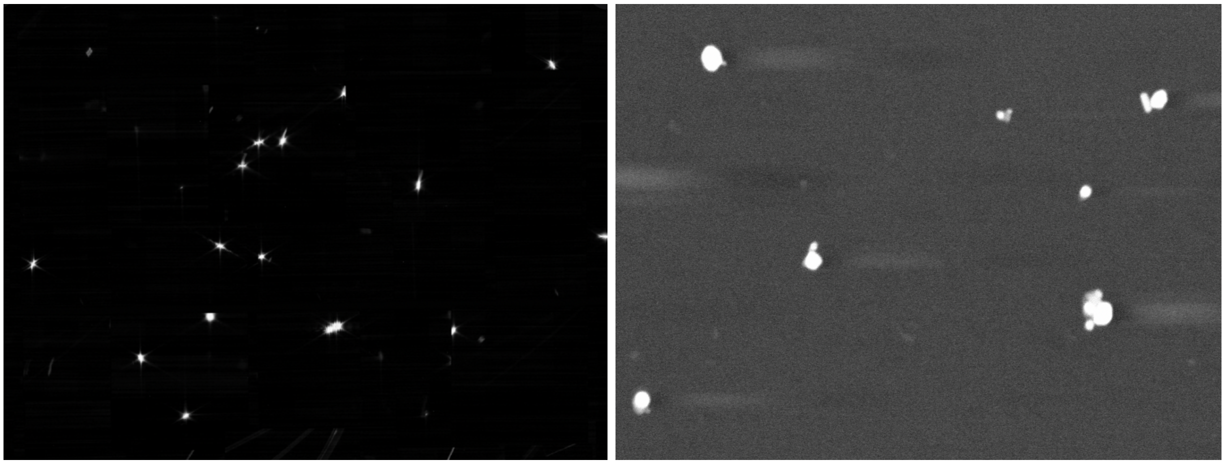


Image of galaxy clusters (left, photo credit: Webb Telescope) and nanoparticles (right, photo credit: Camden Lab)



Dark field microscopy images of nanoparticles. Photo credit: Camden Lab

Teacher Reflection

I completed this lesson with my 5th grade students. They were fascinated with the images, and the most common answer was that they were all pictures of stars. Once we started with the video and the interactive scale image, they were in awe of how something can be so small. It helped that I had previously taught Physical Science, so they were already familiar with things that can be invisible because they are so small. The sugar activity was useful to reinforce the concept that once things become so small, their properties can change. My students' favorite activity was looking at their assigned videos. I had them create a small poster with their group about their video and present it to the class about what they learned about nanoparticles. This activity provided a nice informal assessment for me at the end of the lesson.

Alternative Introductory Lesson: How Small Is Small? Bringing Nanoparticle Research to Your Classroom (K-12: Adaptable)

Standards:

- **2-PS1-3.** Make observations to construct an evidence-based account of how an object made of a small set of pieces can be disassembled and made into a new object.
- **5-PS1-1.** Develop a model to describe that matter is made of particles too small to be seen
- **MS-PS1-2.** Analyze and interpret data on the properties of substances
- **CCSS.ELA.SL.1** (all grade levels) Participate and engage effectively in collaborative conversations with diverse partners about grade-level topics and texts with peers and adults in small and larger groups.

Connections to Nature of Science:

- Scientific knowledge is open to revision in light of new evidence.
- Science is a human endeavor.
- Science addresses questions about the natural and material world.

Connections to Engineering, Technology, and Applications of Science:

- Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.
- The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values and by the findings of scientific research.

Objectives:

Students will be able to understand the relative size of a nanoparticle.
Students will analyze the way properties of a material can change with the size of a particle.
Students will be able to identify different ways that nanoparticles might be used.

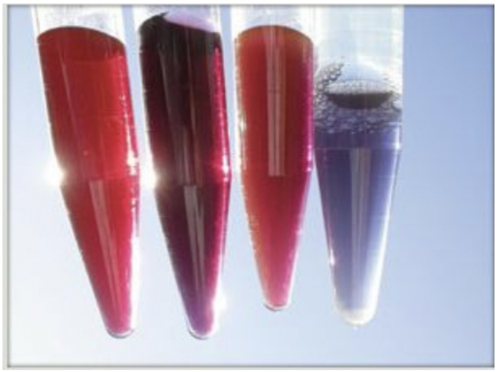
Lesson Plan

Estimated Time: 2 days

Hook (Puzzling Phenomena):
Have students look at the photo below of gold nanoparticles, but do not tell them what is in the photo.

Discussion question:

- *What do you think these are?* Students could list their ideas and predictions on the board or put them on post-its.
- They could also form "I notice… I wonder…" statements.



Gold nanoparticles in transmitted light, source: https://www.webexhibits.org/causesofcolor/9.html

Activity:

- After the hook discussion, do not share with students where the images came from - jump right into the sugar activity.
- Students will work in groups to compare crystalline sugar and powdered sugar to help students connect the idea that when a material is broken down into smaller parts its properties can change.
  - Supplies
    - A small vial or test tube containing crystalline sugar and another containing powdered sugar (one per group)
    - Hand lens – one per group
    - Flashlight or other source of bright light – one per group
    - 2 microscopes *(optional)*
  - Procedure
    - Have students create a 2-column chart in their science notebook to record their observations and comparisons of each substance
    - Have students examine a sample of both crystalline sugar and powdered sugar with a hand lens and record observations; encourage them to also touch/feel the substances.
    - Have students try adding a little water to see what happens and record observations.
    - Set up two microscopes, each with a sample of one of the substances. Groups can take turns viewing each substance and recording

- observations. **NOTE:** If you do not have microscopes, you can find and show students pictures of sugar viewed under a microscope.
    - Discuss student observations and identify that these are basically the same substances, just different sized particles and how the properties change
    - Discuss how each type of sugar might be/is used based on these different properties
    - **OPTION:** Do not initially say what the substances are and just label them as substance one and two; identify the substances after discussion of the properties of each.
- Watch the video about what is nano? Explain what a nanoparticle is (use interactive scale images to better understand the size of things in scale). Explain how the same particle can change color as it is broken into smaller pieces; reveal that the substance in the picture is actually gold, but broken into nanoparticles of different sizes! Relate this back to the sugar activity.
- Introduce the concept of nanotechnology by explaining that scientists use the different properties of nanoparticles to create new materials to solve problems in our world. Assign each group of students a different video to watch to learn about various nanotechnology applications. Students then share with the class what they've learned.

"It was cool and exciting to see how small things can be used to save everyone."

- 7th Grade Student

Assessment:

Exit slip (Formative - index card or Google Form)

1. How can the properties of a material change with the size of the material? Support your answer with evidence from today's class.
2. If you were a scientist in a nanotechnology research lab, what would you want to learn more about or research? Why?

Teacher Reflection

I did this lesson with 6th, 7th, and 8th grade classes, and students at all levels LOVED it. They particularly enjoyed the videos showing how nanotechnology is used in amazing ways in our everyday lives. Their initial guesses regarding what was in the vials in the photo ranged from popsicles to blood! Once they learned that the vials contained nanoparticles, they were intrigued and very curious about the process of "synthesizing the nanoparticles" and how those colorful vials were related to the tiny particles used in the varying applications of nanotechnology. The sugar activity was helpful in developing the concept that the properties of a material can change depending on particle size. Viewing the two types of sugar under the microscope made this especially clear, and I would possibly spend a little more time on that part of the activity next time around. I did this introductory lesson before the science lesson below on light and its properties.

5th Grade Math:
Line Plots - Examining Nanoparticles

Standards:

- **Measurement and Data:** Make a line plot to display a data set of measurements.
- **NGSS 5-PS1-1 Matter and Its Interactions:** Develop a model to describe that matter is made of particles too small to be seen.

Connections to Mathematical Practices:

1. Reason abstractly and quantitatively
2. Model with mathematics
3. Use appropriate tools strategically
4. Attend to precision

Objectives:

Students will create a line plot based on the data they collect from the picture of nanoparticles. Students will discuss observations and make connections about the data.

Materials:

- Students should be divided into groups of 4.
- Chart Paper with chart to record class data
- Markers for recording on chart paper
- Blank paper for line plot - 1 per student
- Copies of the nanoparticle image to the right - enlarged, divided into sections depending how many groups you have. There should be 4 copies of the same section (one for each person in the group).

Nanoparticles from dark field microscopy; photo credit: Camden Lab

Lesson Plan

Estimated Time: 1-2 days

Hook:

- Review definition of nanoparticles as well as how different colors represent different sizes of nanoparticles. Show the image, tell students they will participate in gathering and organizing data.
- Discuss ways we could count the nanoparticles efficiently in table groups.

Activity:

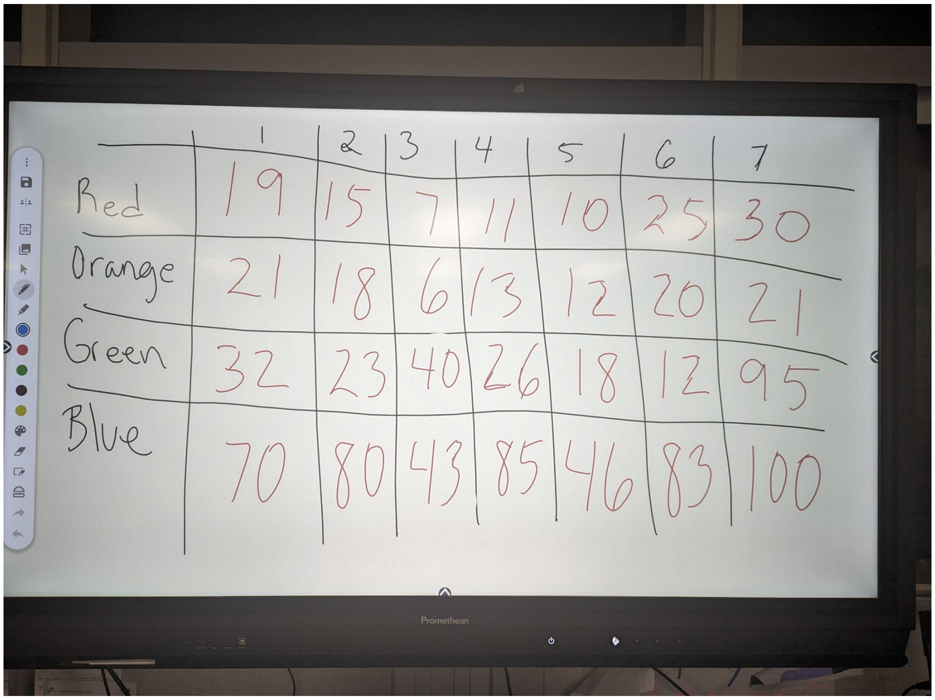
- Give students pictures of nanoparticles (each group should get the same picture). Each student will be counting how many times one color is represented in the picture (blue, green, orange, red).
- Have groups decide who is counting which color, give them 5 minutes to count and record their data on the class chart.
- After the class chart is completed, review sentence frames for discussion.
- Have students think of a sentence that could explain the chart. Share with their table group and/or partner.
    - Some examples are: *I notice there are more ______ than _____. I notice there are fewer _____ than ______. Therefore, __________.*
- Tell students we will be creating a line plot as a visual display of the entire class' data. Pass out paper for line plot. Model drawing a line plot and completing it for 1 color.
- Have students complete the rest of the line plot, checking their work with others at their table.
- Have a class discussion about what they notice.

Assessment:

- Check students' line plots and sentences for accuracy and correct structure/grammar.
- How does this activity help scientists?

Teacher Reflection

My 5th graders were excited to do this activity after completing the introductory lesson about nanoparticles and nanotechnology. We started with a discussion about different ways to gather data using the image from the introductory lesson. The students decided that sorting the nanoparticles by color would help them organize data. There was some horrified complaining when one student suggested that we could count all the nanoparticles. Once we agreed to split up the counting by color, students were much happier. My students sit in table groups of 4, so it was easy to assign each student a different color to count. After students finished counting, they posted their count on a chart I had on the board (see picture below). This allowed everyone to view the numbers of the different colors per table. After we completed the chart, I presented students with the sentence frames to help us analyze the chart. Next, we created a line plot to match the data. We discussed similarities and *differences between the chart with our data and the line plot. We also discussed how scientists might find it helpful to gather data and represent it as a line plot.*



Student data from the 5th grade math activity.

5th-6th Grade Math:
Metric Conversions and Powers of 10

Standards:

- **CCSS.5.MD.1.** Convert among different-sized standard measurement units within a given measurement system (e.g., convert 5 cm to 0.05 m), and use these conversions in solving multi-step, real world problems.
- **CCSS.6.RP.A.3.** Use ratio and rate reasoning to solve real-world and mathematical problems, e.g., by reasoning about tables of equivalent ratios, tape diagrams, double number line diagrams, or equations.
  - **d.** Use ratio reasoning to convert measurement units; manipulate and transform units appropriately when multiplying or dividing quantities.

Connections to Mathematical Practices:

- Make sense of problems and persevere in solving them
- Use appropriate tools strategically
- Attend to precision
- Look for and express regularity in repeated reasoning

Connections to Engineering, Technology, and Applications of Science:

- Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.

Objectives:

Students will be able to understand the relative size of a nanoparticle, as they compare nanometers to meters.
Students will understand the scale of a nanoparticle.
Students will be able to convert nanometers to meters and vice versa.

Materials:

- Rulers
- Meter sticks
- Calculators

"I think the nano activities were cool. They really made me think hard about the sizes of objects. There was science and engineering involved. It interested me because in the future I might want to become an engineer. The activities opened my mind and forced me to REALLY think. I liked this activity." **- 5th Grade Student**

Lesson Plan

Estimated Time: 1-2 days

Activity:

- After the hook discussion, guide students toward making a connection between nanoparticles and powers of 10.
- Review the concept of the metric system and its conversions.
- Students are provided with meter sticks and rulers to get a physical sense of the size of a meter compared with a centimeter and a millimeter. They may use these tools as a reference while answering the questions about nanometers. They may also use calculators.
- Students will work together to answer questions on the conversions worksheet involving conversions of nanometers to units we are more familiar with. These questions are based on the videos and information shared in the Introductory Lesson. Encourage the use of productive talk.

Assessment:

- Worksheet involving metric conversions with nanometers
- Reflection/Exit Slip:
  - How are powers of 10 useful when converting between different metric units of measurement?

Resources:

- Conversions worksheet

Teacher Reflection

I designed and implemented this activity with a group of advanced 5th and 6th grade students as part of my unit on metric conversions. I started with the introductory activity and then used the interactive scale site to review powers of 10 as the basis of the metric system of measurement. Through inquiry and productive talk, the students discussed how they could use the scale provided in the interactive site to fill in the other metric units. Before even giving them the conversion worksheet, they were asking questions about how the different examples in the video would relate to the metric units they are more familiar with. The students asked for meter sticks and rulers to physically compare the different units. When they were presented with the questions about the growth of our fingernails, they immediately started testing out different calculations and asking for calculators so that they could test their theories. The students were much more engaged in this assignment than if I had just assigned them the workbook pages on metric conversions. They enjoyed the opportunity to work together, explore a new topic, and challenge themselves to relate a difficult concept to their everyday lives.

ND STEM
TEACHING FELLOWS

6th-8th Grade Physical Science: Light and Its Properties

Standards:

- **MS-PS4 Waves and Their Applications in Technologies for Information Transfer**
- **PS4.A: Wave Properties**
    - A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. **(MS-PS4-1)**
- **PS4.B: Electromagnetic Radiation**
    - When light shines on an object, it is reflected, absorbed, or transmitted through the object, depending on the object's material and the frequency (color) of the light**. (MS-PS4-2)**
    - A wave model of light is useful for explaining brightness, color, and the frequency-dependent bending of light at a surface between media. **(MS-PS4-2)**

Connections to Nature of Science:

- Science is a human endeavor.
- Science addresses questions about the natural and material world.

Connections to Engineering, Technology, and Applications of Science:

- Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.
- The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values and by the findings of scientific research.

Objectives:

Students will relate changing wavelength and frequency to changes in color.
Students will connect quantum dots with the brightness and color of displays.
Students will analyze the way properties of a material can change with the size of a particle.

Lesson Plan

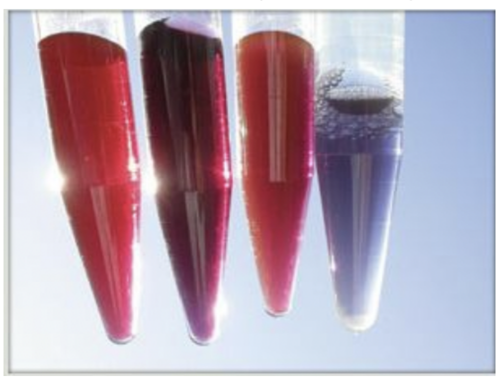
Estimated Time: 2-3 days

Hook (Puzzling Phenomenon):
Have students look at the photo below.

Nanoparticles from dark field microscopy, photo credit: Camden Lab

Discussion question:

- *What is pictured here?* Students could list their ideas and predictions on the board or put them on post-its.
- They could also form "I notice… I wonder…" statements.
- After the hook discussion, share with students that the picture is also gold nanoparticles but a different view (review image below from previous lesson)



Gold nanoparticles in transmitted light, source: https://www.webexhibits.org/causesofcolor/9.html

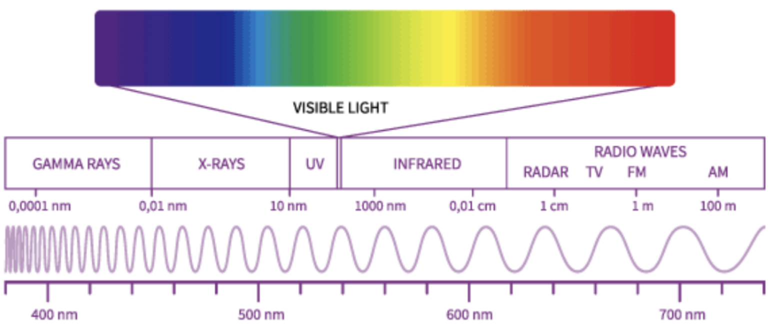
---

"We saw gold nanoparticles, which was very cool, and it looked like nothing I have ever seen before." - 7th Grade Student

---

Activity:

- Students will use the PhET simulation called "Color Vision" to explore how visible light can be changed with filters and by using different colored light together: https://phet.colorado.edu/sims/html/color-vision/latest/color-vision_en.html
  Students will work through the simulation and answer the following questions in their science notebook that will then be discussed together:
  - *What do you notice about the particles that make up a beam of "white" light?*
  - *What happens to the particles of color when you use different colored filters?*
  - *What happens if the bulb color does not match the filter color?*
  - *What do you notice when you change the levels of blue, green, and red light?*
  - *What color is visible light (the light we get from the sun and other lights)? Use evidence from the activity to support your answer.*
- Introduce the idea that visible light is just one kind of light, and that changing wavelength and frequency is what causes changes in the spectrum of light energy and changes in color in the visible light spectrum (use the diagrams below to help).



Color	Wavelength
violet	380–450 nm
blue	450–495 nm
green	495–570 nm
yellow	570–590 nm
orange	590–620 nm
red	620–750 nm

- Talk about the microscope used in the introductory sugar activity and how they use visible light: wavelengths of light (380-750 nm of light). Compare those measurements to the size of gold nanoparticles (40-50 nm) - recognize that visible light microscopes will not allow us to see particles that small.
- Introduce dark field microscopy: scattering of light against a dark background to see nanoparticles:
  - Ask students to brainstorm with their elbow/table partner and then share why they think there are so many different colors in the image of the nanoparticles from the start of the lesson.
- Review from the previous lesson how the properties of sugar changed on a smaller scale. Discuss how nanostructures that are so small that they have different optical and electrical properties than larger particles; so, light given off can be altered very carefully by changing the size, shape, or material of a nanoparticle.

"I learned that unexpected changes happen when particles get nano!"

- 6th Grade Student

- Look at nanoparticles from the dark microscopy image again and discuss again the question of why there are so many different colors. Watch the short video on quantum dots: https://www.youtube.com/watch?v=oXyTsx_XRnw
- Review from the videos what a quantum dot is: Quantum dots absorb light of a range of wavelengths and emit light of a different, defined wavelength depending on their size or composition. (Note: It is this property that makes quantum dots useful in display devices, such as televisions, because they create brighter, more vivid images.)

Figure 2. Images of conventional (left) and quantum dot (right) LCD displays (**image source**)

Source: https://news.samsung.com/global/why-qled-matters-for-4k-hdr-content

Assessment:
Formative: Answers to the discussion questions from the PhET simulation; elbow partner discussion

Notes and Resources:
- Optical vs. dark field microscopes - visible light vs. scattering of light against a dark background
- The resolution of the optical microscope is restricted by the wavelength of visible light, which thus precludes atomic-scale imaging.
- Look at wavelengths of visible light in nanometers and compare to very small things (less than 300 nm, shortest wavelength of visible light)
- Nanoparticles cannot easily be seen (poor resolution - can't see details)
- Diffraction different with different sized nanoparticles using dark field
- Diffraction vs. refraction: Refraction is the change in direction of waves that occurs when waves travel from one medium to another. Refraction is always accompanied by a wavelength and speed change. Diffraction is the bending of waves around obstacles and openings. The amount of diffraction increases with increasing wavelength.
- PhET simulation: https://phet.colorado.edu/sims/html/color-vision/latest/color-vision_en.html

- Nanotechnology videos: https://www.nsf.gov/news/mmg/index.jsp?series_name=Nanotechnology:%20Super%20Small%20Science
- Background on quantum dots and their use in screens: https://avantama.com/quantum-dot-tv/
- More background on quantum dots: https://quantum-solutions.com/blog/how-quantum-dots-enhance-the-color-spectrum-in-lcd-displays/

Teacher Reflection

I did this lesson with my two 7th grade classes in the context of a unit on waves. This was after students participated in the "Alternative Introductory Lesson" described above. The students LOVED the introductory lesson (especially the videos showing how nanotechnology is used in amazing ways in our everyday lives) and were very intrigued by the photo of the nanoparticles taken with the dark field microscope. The students enjoyed using the PhET simulation, and the discussion/reflection questions were helpful; students were able to recognize that viewing particles on the nanoscale would require something other than an optical microscope and were eager to again have the chance to see the effects of using materials at the nanoscale for a desired effect.

I started the lesson with the dark field microscope photos of nanoparticles and circled back around to it later in the lesson. If a more "linear" approach works better for an individual teacher, the order of things could be modified. The lesson could begin with the following question for students to answer in their science notebook: "What color is visible light (the light we get from the sun and other lights)? Use evidence to support your answer." *Students could then complete the PhET simulation and the discussion/reflection questions and analyze the diagrams describing how light changes due to wavelength. The lesson could then continue (possibly on day two) with the Hook/Puzzling Phenomenon. After discussion of the hook, the class would again review the diagram of the wavelengths of visible light and then move forward with the rest of the lesson.*

An addition/extension that I would make to this lesson is to include an opportunity for students to research other uses of quantum dots to wrap up the lesson.

8th Grade Math: Scientific Notation - Analyzing Nanoparticle Size

Standards:

- **CCSS.ELA.SL.1.** (all grade levels) Participate and engage effectively in collaborative conversations with diverse partners about grade-level topics and texts with peers and adults in small and larger groups.
- **MAFS.8.EE.1.3.** Use numbers expressed in the form of a single digit times an integer power of 10 to estimate very large or very small quantities, and to express how many times as much one is than the other.
- **MAFS.8.EE.1.4.** Perform operations with numbers expressed in scientific notation, including problems where both decimal and scientific notation are used. Use scientific notation and choose units of appropriate size for measurements of very large or very small quantities (e.g. use millimeters per year for seafloor spreading).

Connections to Nature of Science:

- Science is a human endeavor.
- Science addresses questions about the natural and material world.

Connections to Engineering, Technology, and Applications of Science:

- Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.
- The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values and by the findings of scientific research.
- Software applications, such as imageJ, can be used to manipulate and analyze images from microscopes.

Objectives:

Students will be able to understand the relative size of a nanoparticle.
Students will be able to identify different ways that nanoparticles might be used.
Students will understand the scale of a nanoparticle.

Lesson Plan

Estimated Time: 2 days

Activity:

- After the hook discussion, guide students toward making a connection between nanoparticles and scientific notation and discuss why scientific notation would be helpful in this real-world context.
- Review the concept of scientific notation and how it can be used to describe very large and very small numbers.
- Explain that in today's lesson we will be using technology to help us find measurements that we can then express in scientific notation.
- Introduce students to imageJ free software program, which is used by graduate students to analyze images from different types of microscopes. (An instruction guide can be found here.)
- Complete nano activity sheet using imageJ software to analyze measurements of nanoparticles and express them in scientific notation. This sheet also functions as a guide. **NOTE:** The Drive folder referenced in Step 1 on the activity sheet is linked here.
- **Extension:** Have students research the uses of different shapes and sizes of nanoparticles. *Why might it be important for scientists and researchers to know the size of the particles they have synthesized?*

"The nano activities we learned in class were really fun and interesting to learn about because it gives me a better understanding of STEM and made me want to learn more about nanoparticles. I learned many things about nanotechnology and I would say my favorite was learning about how these particles contribute to mathematics and science because I love math and it's really fun to learn about."

- 7th Grade Student

Assessment:

- Scientific notation concepts assessed through the nano activity sheet.
- Extension activity - formative assessment of student's understanding of nanoparticles and how they are used in the real world.

Resources:

- Nano activity sheet
- ImageJ program link and imageJ instructions guide
- Google Drive folder of Scanning Electron Microscope (SEM) images of nanoparticles

Teacher Reflection

I taught this lesson to a small group of advanced 7th grade students and to a separate class of 8th grade students. We started with the introductory lesson and extension activity of watching the videos about nanotechnology applications. The students were engaged in the discussion and some were even able to make the connection between nanoparticles and scientific notation before I even introduced this specific lesson. We did not complete the optional sugar activity section of the introductory lesson, as our time was limited to Math class, but I think it would have made the concept more engaging for the students if I had been able to fit it in.

The students did need a lot of guidance with using the imageJ software program, even with the step-by-step instructions. Having more students working together in a group proved to be helpful as they were able to troubleshoot a bit better. I also realized that some students needed a refresher on the meaning of scale, so it would probably be helpful to use a sample image at first and explain the different parts of the image before having them start the guided activity.

One modification that I made between groups was that the second time I taught the lesson, I shared pictures of the different types of microscopes used to collect the images (dark field microscope and scanning electron microscope) in between the introductory lesson and this one. It helped the students to better understand where the images came from before starting to collect measurements, and ultimately made them more interested in the activity.

Additional Resources

Resource	Link	Description	Application
Nanotechnology videos	https://www.nisenet.org/catalog/intro-nano-video https://www.nsf.gov/news/mmg/index.jsp?series_name=Nanotechnology:%20Super%20Small%20Science https://vimeo.com/13370718?embedded=true&source=vimeo_logo&owner=3490561	Intro video explaining the concept of nano Video library of videos focusing on different applications of nanotechnology Video discussing the benefits and hazards of nanosilver	This video is used in the introductory lessons to provide background. This link is used during the introductory lessons as a research/extension component. This video may be useful when discussing pros and cons of nanotechnology.
Article: What Are Nanoparticles?	https://www.twi-global.com/technical-knowledge/faqs/what-are-nanoparticles	Article defining what a nanoparticle is and explaining why the properties of a material at the nanoscale change; some uses of nanotechnology are described	This article is used to increase teacher background about nano.
Article: Nanoscience vs Nanotechnology—Defining the Field	https://pubs.acs.org/doi/10.1021/acsnano.5b01418	Article defining terms and providing background information about nanoscience and nanotechnology	This article is used to increase teacher background about nano.
Folder with SEM Images of various nanoparticles	SEM Images	Folder containing different images of silver and gold nanoparticles as taken with a SEM	These images are needed for the 8th Math activity but can also be shown in all lessons for extra nano images.
Size and Scale Interactive	https://learn.genetics.utah.edu/content/cells/scale/	Website containing an interactive model to demonstrate size and scale	This model can be used in the introductory lesson to show students the size of nanoparticles compared to other items.